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Effects of Sodium Pentachlorophenate on Survival and Energy Metabolism of Embryonic and Larval Steelhead Trout

GARY A. CHAPMAN and DEAN L. SHUMWAY

Abstract—A study was conducted to determine the effects of technical grade sodium pentachlorophenate (Na-PCP) on the early developmental stages of the steelhead trout *(Salmo gairdneri)*. In an experiment where embryos were exposed to Na-PCP from fertilization to hatching, 100% mortality occurred within one week after fertilization at concentrations down to 300 ppb (μg/l); within 24 hours post-hatch, 100% mortality occurred down to 50 ppb of Na-PCP. Alevin dry weight at hatch was decreased by exposure to Na-PCP and hatching was delayed. In 5-day tests, alevins usually died within 24 hours at concentrations down to 200 ppb, but little mortality occurred at lower concentrations.

Continuous exposure to Na-PCP from fertilization to complete yolk absorption produced 100% mortality at 40 ppb Na-PCP but little mortality at 20 or 10 ppb. However, in water containing 5 mg O_2/l, 20 ppb Na-PCP was 100% lethal and at 3 mg O_2/l, 10 ppb was 100% lethal. Little mortality occurred at these oxygen levels in the absence of Na-PCP. Oxygen consumption rates of alevins in 40 ppb Na-PCP were higher than those of control alevins. Exposure to Na-PCP reduced yolk utilization efficiency and growth. The bioenergetic data obtained in the study are consistent with the concept that PCP disrupts energy metabolism.

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Introduction

The experiments described in this paper were conducted at Oregon State University to follow survival, growth, development, oxygen consumption, and bioenergetics of steelhead trout *(Salmo gairdneri)* embryos and alevins in media containing sodium pentachlorophenate (Na-PCP). The terminology applied to life history stages is as follows:

embryo — developmental stages to the moment of hatching

alevin — developmental stages from hatching until all yolk has been absorbed

The embryonic and alevin stages each comprise roughly one-half of the developmental period. Approximately halfway through the alevin period, the alevin attains a stage called the "swim-up." Once the swim-up stage is attained, the alevins swim freely about in the water.

The total reliance upon yolk for nutrition lasts throughout the embryonic stages and through the alevin period up to the swim-up stage. The swim-up alevin can utilize a dual source of nutrition, yolk and exogenous food.

A number of laboratory studies on the growth and bioenergetics of embryos and alevins of salmonids have been conducted. Most notable are the studies by Smith (1947, 1952, 1958), Gray (1926, 1928), and the series of experiments summarized by Hayes (1949). Almost all investigations of this type have taken advantage of the closed nutritive system afforded by the yolk supply and have routinely denied the swim-up alevins a supply of exogenous food. Such an approach simplifies the analysis of growth data by eliminating the need to determine food consumption and assimilation efficiencies.

The growth of salmonid alevins denied exogenous food is limited by the amount of yolk present and the relative proportions of the yolk which are utilized for tissue elaboration, maintenance, and activity. Thousands of eggs can be obtained from a single fish and fertilized at the same time, giving a population of embryos with essentially uniform size, age, and genetic composition. With such a population, the amount of yolk is rather constant between eggs, and therefore, the growth potential of each embryo is the same. Growth and bioenergetic parameters of embryos and alevins from such a population can be measured under a variety of conditions with relatively little variation within a given sample, thus permitting the detection of rather small changes in these parameters.

Experimental Animals

Eggs of the steelhead trout, a sea-run form of the rainbow trout, were obtained from trout hatcheries in Oregon and transported to the laboratory within 2 hours of fertilization. Some batches of eggs were immediately used in experiments while others were held in running water in 2-liter separatory funnels. Just prior to hatching, the eggs held in the funnels were transferred to shallow troughs. The newly hatched alevins were held in the troughs until used in the experiments. Aerated water at 10°C was continuously supplied to the troughs and separatory funnels at rates of about 500 ml/min.

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16. ABSTRACT

A study was conducted to determine the effects of technical grade sodium pentachlorophenate (Na-PCP) on the early developmental stages of the steelhead trout (Salom gairdneri). In an experiment where embryos were exposed to Na-PCP from fertilization to hatching, 100% mortality occured within one week after fertilization at concentrations down to 300 ppb (g/l); within 24 hours posthatch, 100% mortality occured down to 50 ppb of Na-PCP. Alevin dry weight at hatch was decreased by exposure to Na-PCP and hatching was delayed. In 5-day tests, alevins usually died within 24 hours at concentrations down to 200 ppb, but little mortality occured at lower concentrations. Continuous exposure to Na-PCP from fertilization to complete yolk absortion produced 100% mortality at 40 ppb Na-PCP but little mortality at 20 or 10 ppb. However, in water containing 5 mg O_2/1, 20 ppb Na-PCP was 100% lethal and at 3 mg O_2/1,10ppb was 100% lethal. Little mortality occured at these oxygen levels in the absence of Na-PCP. Oxygen consumption rates of alevins in40 ppb Na-PCP was higher than those of control alevins. Exposure to Na-PCP reduced yolk utilization efficiency and growth. The bioenergetic data obtained in the study are consistent with the concept that PCP disrupts energy metaloblism.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Sodium Pentachorophenate Trout, Steelnead Aquatic animals Fishes Vertibrates Fresh water fishes		06/C,K,F,S

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Sodium Pentachlorophenate

A single lot of Santobrite® (Monsanto Chemical Company) containing a minimum of 90% sodium pentachlorophenate (Na-PCP) was used in all experiments. All concentrations of Na-PCP were calculated on the basis that Santobrite had a purity of 100% Na-PCP.

Static Tests

Static toxicity tests were conducted in shallow glass vessels, 25 × 25 × 5 cm. The embryo and alevin tests were performed at 10 and 15°C in constant temperature rooms, respectively.

An embryo test, lasting about 1 month, was begun in the field 15 minutes after the eggs were fertilized; the eggs were immediately returned to the laboratory and the test was terminated shortly after hatching occurred. The test solutions were constantly aerated and were renewed every other day. Unfertilized eggs and eggs containing dead embryos were removed when the solutions were changed.

A series of 5-day toxicity tests was conducted using alevins hatched from the eggs of a single female. Tests were started when alevins were 3, 8, 14, and 22 days old (age from hatch). A second series was similarly performed using 4-, 10-, and 18-day old alevins from another female. Alevins were transferred to fresh solutions once or twice daily, depending on the experiment; this procedure was adopted to minimize the effects of detoxification and deoxygenation of the solutions by the alevins. Dead alevins were removed when the solutions were renewed.

Flow-Through Tests

In all experiments, filtered stream water (pH about 7.8) was brought into a constant temperature room through polyethylene pipes and into a head box via a float valve. The water in the head box was aerated and heated.

The apparatus used in experiments with Na-PCP consisted of a series of components integrated into a system to deliver water with desired dissolved oxygen and Na-PCP concentrations to respirometers designed for rearing salmonid embryos and alevins (Chapman, 1969).

At the beginning of an experiment, approximately equal numbers of alevins (or eggs) were placed into each respirometer. In addition, a representative sample of alevins or eggs was taken to determine the mean weight of the alevins and the mean weight of yolk present at the start of each experiment. Dead alevins were usually removed and counted daily. Thirty to 250 alevins, depending on the number remaining in each respirometer, their weight, and degree of development, were removed from each respirometer at intervals spaced so that changes in alevin and yolk weights could be adequately defined.

The alevins in each sample were divided into two sub-samples and killed in a

solution of MS-222. The alevins in one sub-sample were blotted on paper towels, counted, and weighed in aggregate. Alevins in the other sub-sample were handled in the same manner except that their yolk was removed prior to weighing. The removal of yolk from young alevins was easily accomplished by excising the entire yolk sac. However, as the amount of yolk diminished and significant dermal overgrowth of the yolk sac occurred, it became necessary to make a mid-ventral slit along the body cavity in order to ensure complete removal of yolk and prevent the excision of significant quantities of non-yolk tissue such as skin and viscera. After being weighed, the samples were dried at 75 to 80°C for 5 days, cooled in a desiccator, and weighed again. The amount of yolk present at a given time was determined by taking the difference between the weight of alevins with yolk and the weight of alevins from which the yolk had been excised.

In several experiments the caloric content of alevin and yolk tissue was routinely determined using bomb calorimetry. Dried samples were finely ground and 100 to 200 mg portions combusted in a Parr Model 1411 bomb calorimeter. At least two determinations were made on each sample, and duplicate samples usually yielded results within 1%. Caloric values for yolk were calculated from results obtained on samples of alevins with yolk and of alevins from which the yolk had been excised.

Oxygen determinations were made by using the azide modification of the Winkler method. Determinations of oxygen consumption were normally made twice a day, once in the morning and once in the late afternoon. Oxygen consumption rates were calculated and expressed as mg O_2/g alevin dry weight/hr.

Results of Static Tests

Embryos

All eggs held in Na-PCP concentrations of 300 ppb (μg/l) or greater died during the first week of development. Na-PCP concentrations of 50, 80 and 180 ppb caused 100% mortality, with most of the mortality occurring after hatching at 50 and 80 ppb and before hatching at 180 ppb. The dry weight at hatch of alevins reared in Na-PCP was markedly less than that of control alevins.

Alevins

During the 5-day static toxicity tests with alevins, most mortality occurred within 24 hours. Concentrations of Na-PCP higher than 300 ppb always caused 100% mortality within 12 hours. The lowest concentration which produced 50% mortality in any of the toxicity tests was 150 ppb; the highest concentration which failed to produce 50% mortality was 250 ppb.

The relationship between Na-PCP concentration in the static toxicity tests and the time required to produce 50% mortality of steelhead trout alevins is shown in Figure 1. Data from similar tests with chinook salmon *(Oncorhynchus tshawytscha)*

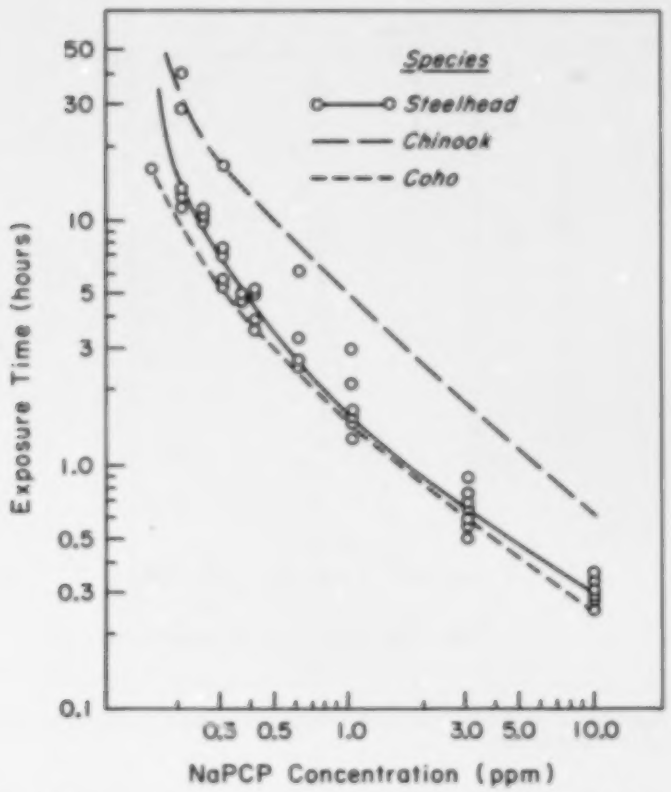

Figure 1. The time required to produce 50% mortality of alevins of three species of salmonids at the indicated concentrations of Na-PCP. All data points are for steelhead trout. Chinook and coho salmon curves were fitted by eye to data from 5 tests with chinook salmon and one test with coho salmon.

alevins and coho salmon *(O. kisutch)* alevins are included for comparison. Alevins of steelhead trout, coho salmon, and chinook salmon appeared to be similar in their response to Na-PCP, although chinook alevins survived somewhat longer at most concentrations.

Results of Flow-Through Tests with Trout Alevins

Dissolved Oxygen and Na-PCP Toxicity

The mortality rate of alevins exposed to 40 ppb Na-PCP was highest at a dissolved oxygen concentration of 3 mg/l (Fig. 2). Although no mortality was seen

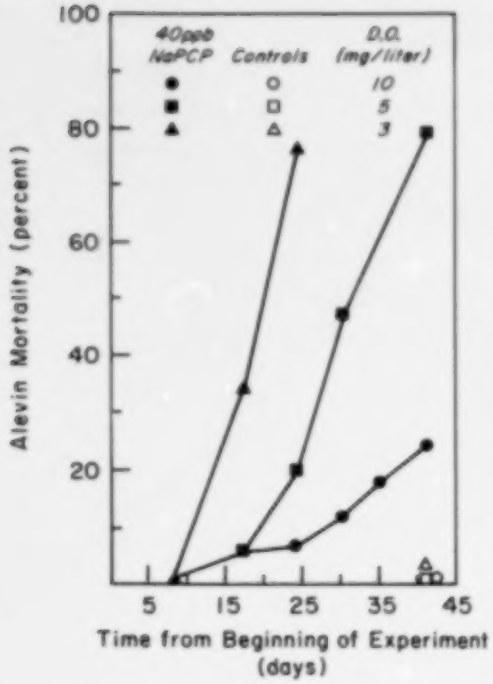

Figure 2. The effect of dissolved oxygen concentration on the mortality of steelhead trout alevins reared in 40 ppb Na-PCP.

within the first 8 days of exposure to 40 ppb Na-PCP, after 24 days of exposure the alevins reared at 3 mg O_2/l suffered 76% mortality compared to only 20% at 5 mg O_2/l and 7% at 10 mg O_2/l. After 41 days, mortality in 40 ppb Na-PCP was 79% at 5 mg O_2/l and 24% at 10 mg O_2/l. The dissolved oxygen concentrations were of themselves nonlethal, as observed in control alevins.

Low levels of dissolved oxygen had a slight effect on the growth of control alevins, while Na-PCP treated alevins exhibited less growth (Fig. 3). The time required to attain maximum weight was prolonged at 5 mg O_2/l and 3 mg O_2/l. The maximum dry weight gain of alevins reared at 40 ppb Na-PCP at the high dissolved oxygen concentration was 22.5% lower than that attained by control alevins. Alevins reared in 40 ppb Na-PCP at 5 and 3 mg O_2/l never attained maximum weight before the last surviving alevins were removed; however, the nature of the growth curve of the surviving alevins reared at 5 mg O_2/l suggests that the final weight noted was near the maximum.

The effects of dissolved oxygen concentration and 40 ppb Na-PCP, both singly and in combination, on the efficiency of yolk utilization were studied. The efficiency

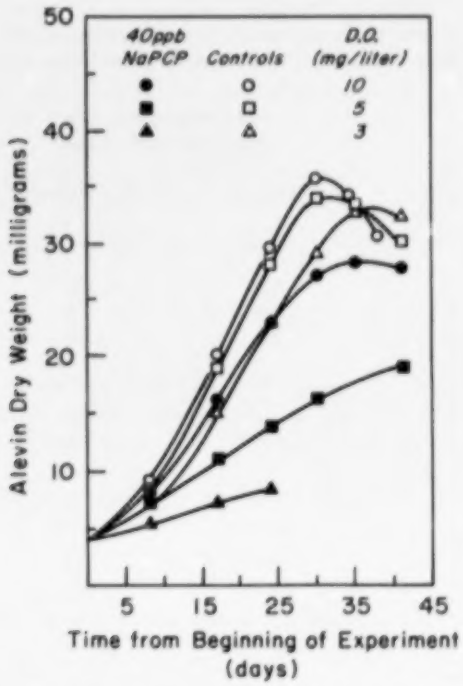

Figure 3. The effect of dissolved oxygen concentration on the growth (dry weight) of steelhead trout alevins reared under control conditions or at 40 ppb Na-PCP.

reduction at 40 ppb Na-PCP was greater at low O_2 concentrations, while low dissolved oxygen concentrations alone only slightly reduced the efficiency of yolk utilization.

The relative contributions of increased yolk catabolism rates and decreased yolk uptake rates to the reduced efficiencies of yolk utilization seen under conditions of exposure to 40 ppb Na-PCP at various dissolved oxygen concentrations are indicated in Table 1. In all cases, an increased rate of yolk catabolism was the primary factor in decreasing the yolk utilization efficiency in alevins exposed to Na-PCP. In the absence of Na-PCP, dissolved oxygen concentrations of 5 and 3 mg/l had no clear-cut effect on the rates of yolk uptake or yolk catabolism.

Exposure of alevins to water of reduced oxygen concentration in the presence or absence of 40 ppb Na-PCP caused the caloric increments of the alevins to be lower than that of control alevins reared at 10 mg O_2/l. The magnitudes of the reductions in caloric increment were similar to those produced in dry weight increment with slight reductions occurring in control alevins at oxygen concentrations of 5 and 3 mg/l and greater reductions in alevins exposed to 40 ppb Na-PCP, especially at lower oxygen concentrations (Table 2).

TABLE 1. The Effect of Dissolved Oxygen Concentration and Na-PCP on Yolk Uptake and Yolk Catabolism of Steelhead Trout Alevins[a]

O_2 (mg/l)	Mean yolk uptake rate (mg yolk/g alevin/day)	
	Control	40 ppb Na-PCP
10	85	82
5	89	71
3	84	73
	Mean yolk catabolism rate (mg yolk/g alevin/day)	
	Control	40 ppb Na-PCP
10	16	20
5	20	26
3	15	45

[a]Alevins exposed to 40 ppb Na-PCP for 24 days.

TABLE 2. The Effect of Dissolved Oxygen Concentration on the Growth and Growth Efficiency (Dry Weight and Caloric) of Steelhead Trout Alevins Reared Under Control Conditions or at 40 ppb Na-PCP

	O_2 (mg/l)	Maximum gain		Percent reduction		Efficiency		
		wt (mg)	cal (cal)	wt	cal	wt (%)	cal (%)	cal/wt[a]
Controls	10	31.5	168.9	—	—	82.9	75.2	0.91
	5	29.7	155.2	5.5	8.0	80.3	69.8	0.87
	3	28.6	154.5	9.1	8.5	78.6	70.0	0.89
40 ppb Na-PCP	10	24.0	125.6	23.8	25.6	65.0	56.8	0.87
	5	14.9	77.2	52.7	54.3	55.2	48.6	0.88
	3	4.2	21.7	85.3	87.2	38.5	30.1	0.78

[a]The ratio between caloric efficiency and weight efficiency.

The efficiency of yolk utilization for growth was lower on a caloric basis than on a dry weight basis. The ratios between caloric efficiencies and dry weight efficiencies were 0.89 ± 0.02 under all rearing conditions except 40 ppb Na-PCP at 3 mg O_2/l where the ratio was 0.78.

Oxygen Consumption

The oxygen consumption of alevins was highest during the first week after hatching, declined steadily throughout the period of alevin growth, and reached a minimum when the alevins attained maximum dry weight (Fig. 4). Once alevins started to lose weight, the oxygen consumption rate increased sharply. The oxygen consumption rates of most groups of alevins showed a positive correlation with growth rate (mg growth/gram dry weight/day). The oxygen consumption rates of alevins exposed to 40 ppb Na-PCP were higher than the oxygen consumption rates of control alevins (Fig. 5). Oxygen consumption rates of Na-PCP exposed alevins were also higher than controls when related to age and to a lesser degree when related to weight (Fig. 6).

The effects of 40 ppb Na-PCP and various concentrations of dissolved oxygen on the relationship between alevin growth and the cumulative quantity of oxygen consumed per alevin are shown in Figure 7. Control alevins reared at 10, 5, and 3 mg O_2/l utilized nearly identical quantities of oxygen in the attainment of a given

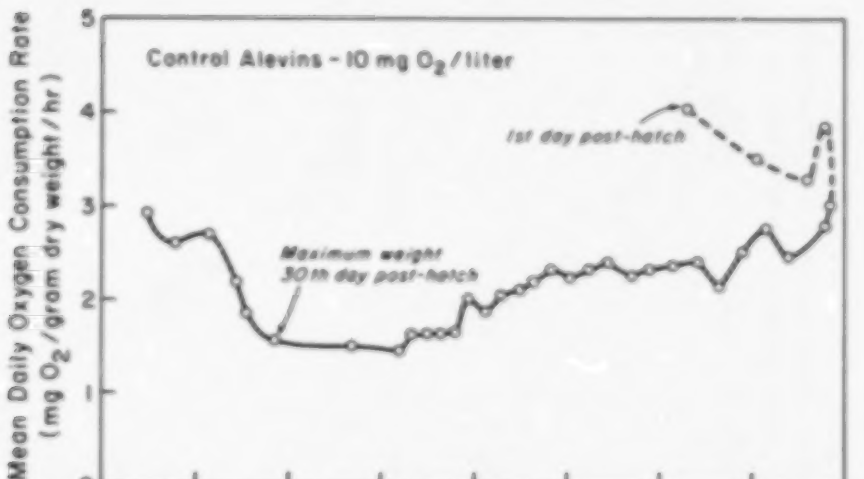

Figure 4. Relationship between growth rate and oxygen consumption rate of steelhead trout alevins reared under control conditions.

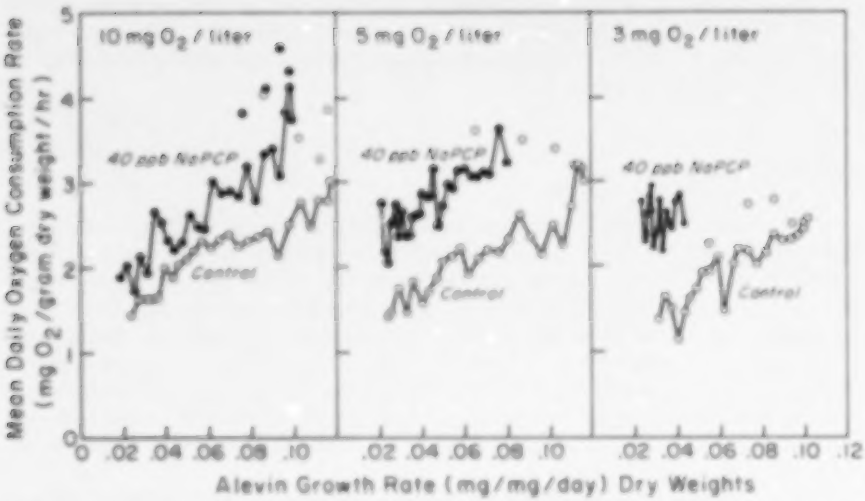
10 mg O2 / liter
5 mg O2 / liter
3 mg O2 / liter
40 ppb NaPCP
Control
Mean Daily Oxygen Consumption Rate (mg O2 / gram dry weight / hr)
Alevin Growth Rate (mg/mg/day) Dry Weights

Figure 5. Effects of 40 ppb Na-PCP on the relationship between growth rate and oxygen consumption rate of steelhead trout alevins reared at different oxygen levels.

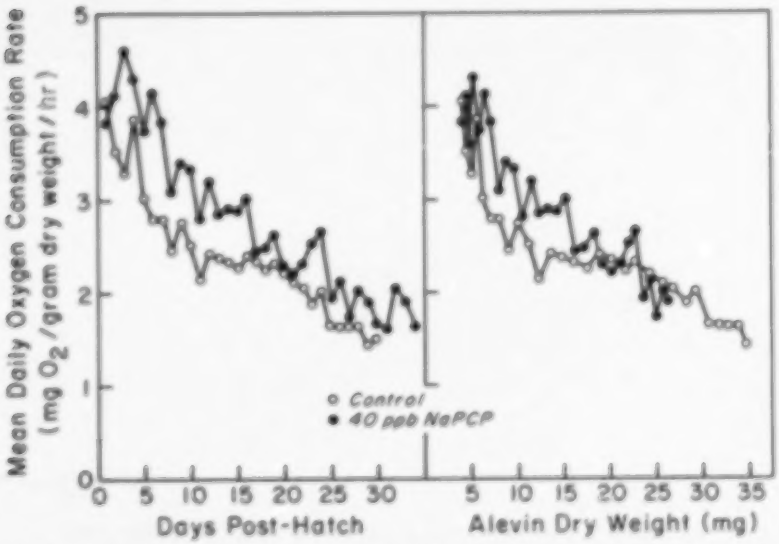

Figure 6. Effects of 40 ppb Na-PCP on the relationships between oxygen consumption rates and age (days post-hatch) and alevin dry weight.

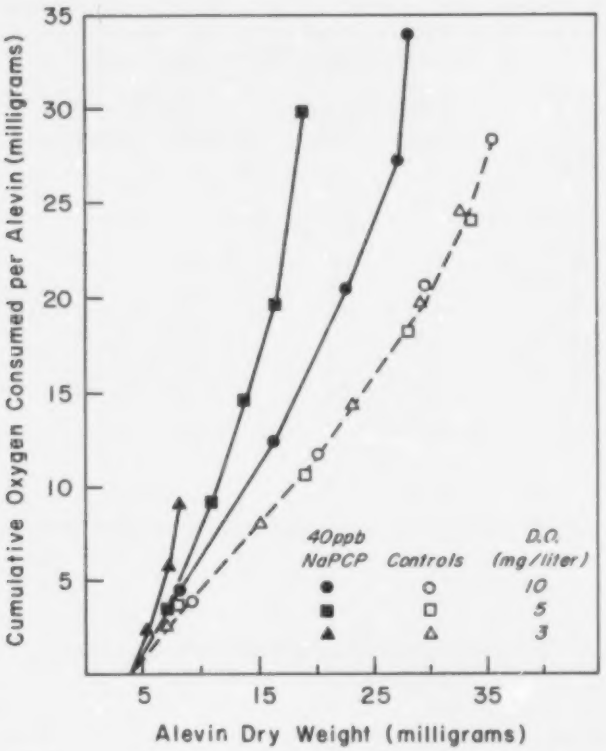

Figure 7. The effect of 40 ppb Na-PCP and various dissolved oxygen levels on the relationship between the amount of oxygen consumed and the dry weight attained by steelhead trout alevins.

weight. Alevins reared at 40 ppb Na-PCP consumed greater quantities of oxygen in growing to a given weight than did control alevins. The lower the dissolved oxygen concentration, the greater the amount of oxygen consumed by Na-PCP-reared alevins in attaining a given weight.

The exposure of alevins to Na-PCP and the resultant increase in metabolic demands disrupted the normal bioenergetic pattern of tissue elaboration and yolk catabolism (Table 3). Typically, control alevins utilized primarily lipids for energy demands, reserving protein for tissue elaboration. Alevins exposed to Na-PCP apparently were forced to use a considerable portion of yolk protein for energy production. Yolk lipid (ether extractable) had a heat of combustion of about 9.1 Kcal/g while that for lipid-free yolk was approximately 5.2 Kcal/g. The yolk material used for energy in control alevins had a heat of combustion of 8.5 to 9.1 Kcal/g while that used by Na-PCP exposed alevins was 6.7 to 7.4 Kcal/g. Exposure to Na-PCP slightly reduced the caloric content of alevin tissue elaborated, with

TABLE 3. Heat of Combustion of Yolk Material Utilized for Energy and of Alevin Tissue Elaborated During the Alevin Growth Phase (from Hatch to Indicated Age Post-Hatch)

Treatment		Yolk catabolized		Tissue elaborated		Age
Na-PCP (ppb)	O_2 (mg/l)	Kcal/g	cal/alevin	Kcal/g	cal/alevin	days
0	10	8.6	56	5.4	169	30
0	5	9.1	67	5.2	155	30
0	3	8.5	66	5.4	155	35
40	10	7.4	96	5.2	126	35
40	5	6.7	82	5.2	77	41
40	3	7.3	50	5.2	22	24

controls having 5.2 to 5.4 Kcal/g as opposed to 5.2 Kcal/g for alevins reared in Na-PCP.

Effects of Continuous Exposure of Developing Steelhead Trout to Na-PCP

In a separate experiment conducted to determine the effect of exposure to Na-PCP from fertilization to the time of complete yolk utilization, eggs and alevins were continuously exposed to 10, 20 or 40 ppb Na-PCP, each in water with dissolved oxygen concentrations of 10, 5, and 3 mg/l (Table 4).

No mortality of eggs was noted until after the eggs were eyed and had been shocked by transferring them to another vessel via a siphon; this action caused sufficient disturbance that dead and nonviable eggs took up water and became opaque. Shocking, which is a routine fish culture operation, was carried out after the embryos were eyed, and hence past the fragile stage. After the dead eggs were removed, the remaining eggs were placed back in the respirometers.

Control embryos at all oxygen concentrations and embryos reared in Na-PCP (10, 20 and 40 ppb) at oxygen levels of 10 and 5 mg/l had about 90% survival at the eyed stage. Approximately one-third of the embryos in each group exposed to Na-PCP at 3 mg O_2/l were dead at the eyed stage. Mortality prior to hatching exceeded 50% only at 20 and 40 ppb Na-PCP at 3 mg O_2/l (Table 4). Hatching of control eggs was delayed by one day at 5 mg O_2/l and by three days at 3 mg O_2/l. Alevins exposed to Na-PCP were delayed in hatching by two days at 5 mg O_2/l and by five days at 3 mg O_2/l.

Control alevins were capable of bursts of swimming activity shortly after hatching, and when at rest, continuous rhythmic movements of mouth, opercles,

TABLE 4. Mortality (%) of Steelhead Trout Exposed to Na-PCP and Low Dissolved Oxygen Concentrations

Na-PCP (ppb)	10 mg O_2/l		5 mg O_2/l		3 mg O_2/l	
	embryo[a]	total[b]	embryo	total	embryo	total
0	9.3	9.3	14.0	14.0	12.8	13.3
10	6.5	9.2	14.5	27.4	36.0	100.0
20	13.8	23.3	15.6	90.8	60.4	100.0
40	11.5	100.0	24.4	100.0	99.6	100.0

[a]Mortality of embryos.
[b]Total mortality occurring from fertilization through the end of the alevin stage.

and pectoral fins could be seen. The alevins which hatched at 40 ppb Na-PCP and 5 mg O_2/l and at 20 ppb Na-PCP and 3 mg O_2/l were moribund; many had only a heartbeat as a vital sign. One-hundred percent mortality of alevins eventually occurred at all concentrations of dissolved oxygen at 40 ppb of Na-PCP and at O_2 concentrations of 3 mg/l at 20 and 10 ppb of Na-PCP (Table 4). Mortality of 90% occurred at 20 ppb Na-PCP and 5 mg O_2/l. About 25% mortality was observed at 20 ppb Na-PCP and 10 mg O_2/l, and at 10 ppb Na-PCP and 5 mg O_2/l. Little or no alevin mortality was noted in any control groups or in 10 ppb Na-PCP and 10 mg O_2/l.

Dissolved oxygen concentrations appeared to have more marked affects than Na-PCP on the dry weights of newly hatched alevins. However, the alevins

TABLE 5. Maximum Dry Weights (mg) Attained by Alevins of Steelhead Trout at Various Concentrations of Dissolved Oxygen and Na-PCP

O_2 (mg/l)	Na-PCP		
	Control	10 ppb	20 ppb
10	41.5 (66)[a]	40.5 (66)	37.7 (71)
5	41.8 (76)	37.4 (86)	26.6 (92)
3	37.9 (81)	——	——

[a]Figures in parentheses indicate the number of days from fertilization required to attain the maximum weight.

surviving a long-term exposure to 20 ppb Na-PCP at 5 mg O_2/l appear to achieve relatively lower maximum weights compared to corresponding controls (Table 5).

Discussion and Conclusions

Embryos and alevins reared in Na-PCP at low O_2 concentrations were more severely affected than those at high O_2 levels. This intensification by low O_2 levels of the effects of toxic materials has been reported before with ammonia, prussic acid, cyanide, and *p*-cresol (Wuhrmann, 1952). This phenomenon is usually ascribed to one of two causes. The first is that at low levels of dissolved O_2 the fish is required to pass more water over the gills in order to obtain a sufficient quantity of O_2, and as a result, absorbs more toxicant via the gills than at higher O_2 levels and lower ventilation volumes. A second explanation is that some chemicals (e.g., prussic acid) have a mechanism of action which produces lesions in gill tissue, and this interferes with normal gas exchange. At low O_2 levels, a partial loss of effective gill area would be more severe than at high O_2 levels.

The mechanism of action of PCP is generally regarded to be one of uncoupling oxidative phosphorylation. The response to partial uncoupling of oxidative phosphorylation or to a more rapid decomposition of ATP would seem to require an increase in O_2 consumption correlated with an increase in substrate oxidation (yolk catabolism) and electron transport. Thus, to obtain a given quantity of ATP, if oxidative phosphorylation were uncoupled to the extent that P:O ratios fell to 2 (normal 3), would require the consumption of 50% more O_2 and the catabolism of 50% more substrate. In fish exposed to PCP, the synergistic effect of low dissolved O_2 concentrations becomes obvious where increased O_2 consumption rates are required to maintain necessary quantities of ATP. Furthermore, the seemingly requisite increase in ventilation volume necessary for a fish to obtain greater amounts of O_2 would also produce the previously mentioned effect of increasing toxicant uptake.

The concept of increased ventilation rates causing the apparently synergistic effect of Na-PCP and low dissolved O_2 is difficult to extend to the case of embryos, since the O_2 uptake of embryos would seem to be passive and dependent on the O_2 concentration gradients between the water, perivitelline fluid and embryo. With the development of the embryonic vascular system and hemoglobin, compensations for living in an environment with low levels of O_2 might conceivably occur. Most compensations which would actually or effectively increase contact between the embryo and the perivitelline fluid would presumably increase the uptake of PCP. Regardless of the mechanism of synergism, there is no doubt that embryos as well as alevins are less able to cope with the stress of Na-PCP when the dissolved O_2 concentration is low.

While determinations of O_2 consumption, growth, and yolk utilization efficiency are obviously too general to produce definitive information as to the mechanism of action of PCP, the bioenergetic data obtained in this study are consistent with the concept that PCP disrupts energy metabolism. Steelhead trout alevins exposed to Na-PCP grew less rapidly than controls due to higher rates of

yolk catabolism and resultant lower efficiencies of yolk utilization, while also exhibiting higher rates of O_2 consumption. Similarly, Webb and Brett (1973) have found that sublethal concentrations of Na-PCP cause reduced growth rate and food conversion efficiency in underyearling sockeye salmon *(Oncorhynchus nerka).* Crandall and Goodnight (1962) found that exposure of mature guppies *(Lebistes reticulatus)* to Na-PCP resulted in higher oxygen consumption, and that long-term (90 days) exposure of newborn guppies to the toxicant resulted in decreased growth, increased mortality, and delayed sexual maturity.

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